Informatik V - Lehrstuhl für Wissenschaftliches Rechnen

Philipp Neumann, neumanph@in.tum.de

Peano: Adaptive Lattice Boltzmann Simulations Using Multiscale Modeling Approaches

The Peano Framework

- Framework for multiscale, parallel PDE solvers using dynamically adaptive Cartesian grids [8]
- Support of arbitrary dimensional grids
- Low memory footprint
- Grid traversal along Peano curve yields high cache efficiency
- Encapsulation of PDE solvers in different components
- Various solvers/applications:
  - Multigrid Poisson solver [8]
  - Finite Element solver for the Navier-Stokes equations [5]
  - Lattice Boltzmann automaton
  - Spatiotemporal multigrid solver for the heat equation

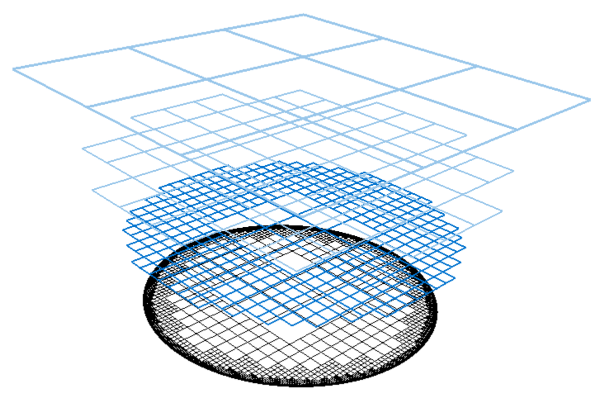

Figure 1: Multiscale representation of the circular domain [8]

Motivation

Micro- and nano-flow systems are controlled by physical effects which appear on different spatial and temporal scales; typical examples are flows through nanopores influenced by Brownian motion effects in the fluid. Therefore, new models and highly adaptive methods are needed to describe all relevant physical effects on the scale of interest.

This poster describes the Peano framework and its Lattice Boltzmann component allowing for adaptive simulations on micro- and nanoscales. The strong modularisation of the different solver steps offers an "easy-to-adapt" environment resulting in simple procedures for the incorporation of new physical models.

The Lattice Boltzmann Method

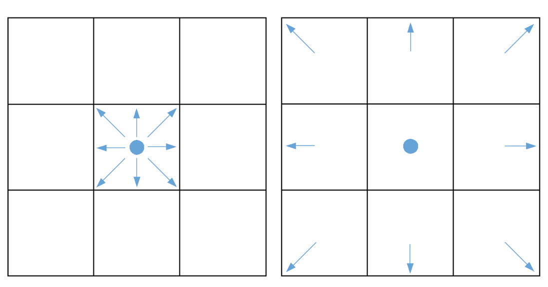

Figure 2: Streaming step in the Lattice Boltzmann algorithm

- Compute probability $f_i(x,t)$ for finding fluid molecules with velocity c_i in small surrounding of x at time t $(i = 1, ..., Q)$
- Modeling of intermolecular collisions by linear collision operator $\Delta(f)$
- Convective transport by streaming populations f_i to neighbouring cells (see Figure 2)
- Update rule:

$$f_i(x + c_i \cdot dt, t + dt) = f_i(x,t) + \Delta_i(f(x,t))$$

Adaptivity Concept

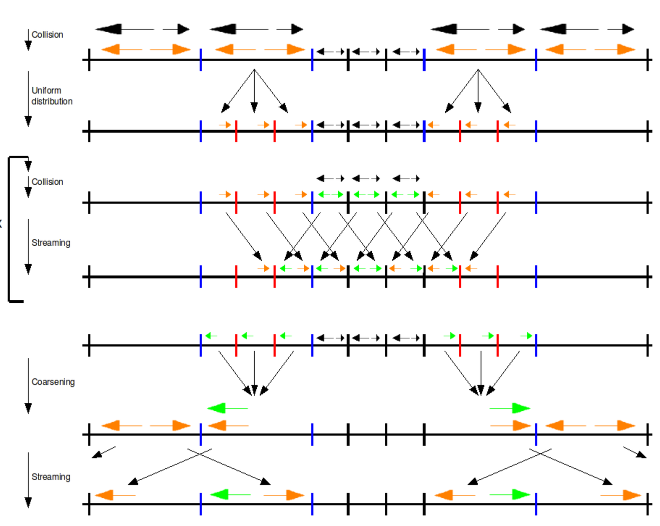

Figure 3: Adaptive approach in Peano

Based on a volumetric, mass-conservative algorithm proposed in [6] (see Figure 3):

- Perform collision on coarse level
- Distribute post-collision particle populations homogeneously on fine level in overlapping region
- Perform collide-stream algorithm on non-overlapping fine cells and streaming on the fine overlapping cells $n = 3$ times (subtimestepping)
- Coarse incoming particle distributions in fine overlapping cells
- Stream on coarse level

Remarks:

- Extension to arbitrary number of levels straight forward
- Number of grid iterations per coarse level timestep in case of L grid levels: 3^{L-1}
- Limit for grid refinement given by stability criteria of Lattice Boltzmann scheme

Lattice Boltzmann Simulations in Peano: An Overview

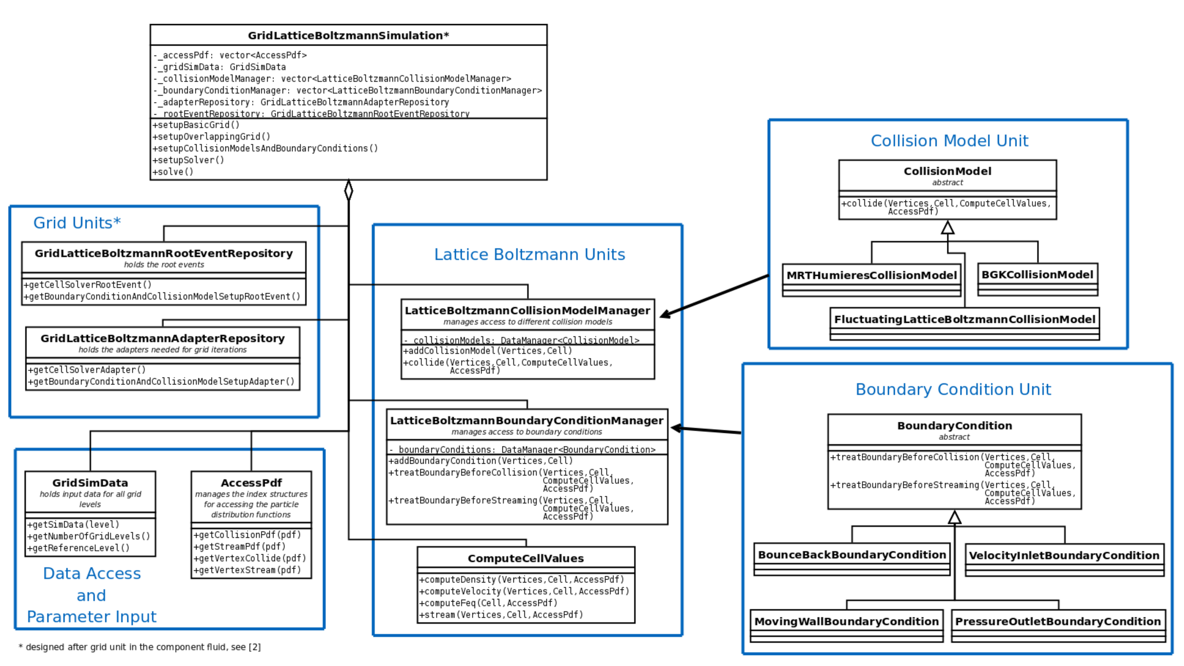

Figure 4: Class diagram of Lattice Boltzmann component for the adaptive grid

- Support of arbitrary direct-neighbour velocity discretisation schemes in 2D/3D (D2D9, D3Q15,D3Q19,D3Q27,...)
- Encapsulation of collision models and boundary condition-treatment in separate management systems
  → Easy exchange/ removal/ extension of the current models/ boundary conditions
- Available collision models:
  - BGK collision model [1]
  - Multiple-relaxation-time model proposed by d'Humières et al. [4]
  - Fluctuating model capturing Brownian motion effects in the fluid [3]
- Free surface extension [7] for regular Cartesian grid
- VTK-compatible multilevel-output for postprocessing

Results

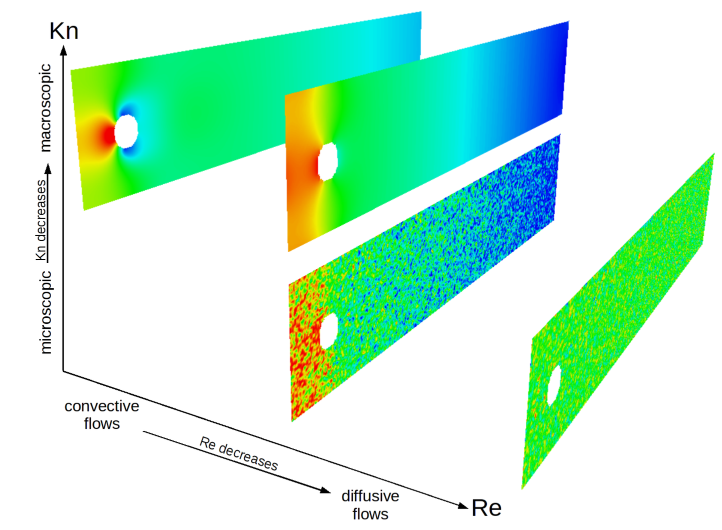

Figure 5: Channel flow around a cylinder at different Reynolds numbers using the BGK and the fluctuating collision model. The latter is used on small scales to capture thermal fluctuations in the fluid and thus accounts for finite Knudsen effects

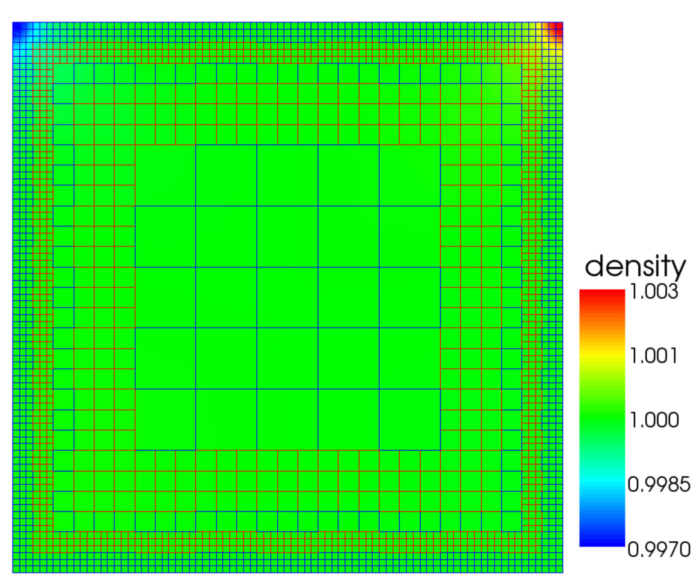

Figure 6: Density field of a driven-cavity at Re=1 with three grid levels using the default refinement of Peano. The red and blue lines mark overlapping and regular fluid cells

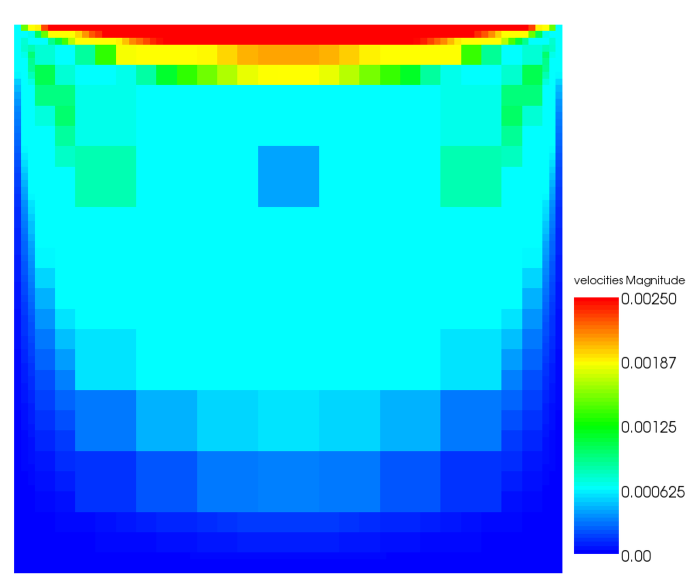

Figure 7: Velocity field of a driven-cavity at Re=1

References

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